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March 8, 1968

LAUNCH PHASE ABORT ANALYSIS FOR A 50-DEGREE ORBITAL INCLINATION TRAJECTORY

By Spaceflight Operations Department

TRW Systems Group

MSC Task Monitor

B. D. Weber

MISSION PLANNING AND ANALYSIS DIVISION

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AAP

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FOREWORD

This report presents the results of a launch phase abort analysis for a high inclination (50 degrees) ascent to orbit trajectory. A similar investigation was conducted previously that used a nonoptimum, high loft ascent trajectory for generation of the launch abort data. Unsafe entry conditions following aborts from this trajectory were found to occur because of the extreme pre-insertion altitude profile. As noted by the findings documented herein, a launch vehicle trajectory characterized by an optimum altitude history produced entry loads within the limits established for manned missions. Other launch abort considerations were also examined to provide a complete preliminary investigation of the effect of a high orbital inclination on suborbital abort procedures.

This report is submitted to satisfy the requirements of MSC/TRW Task AA-26, Subtask 2, Contract NAS 9-4810.

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CONTENTS

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ILLUSTRATIONS

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NOMENCLATURE

AAP	Apollo Applications Program
CM	command module
COI	contingency orbit insertion
CSM	command service module
g	unit of gravitational acceleration
g. e. t.	ground elapsed time
h_p	perigee altitude
IGM	iterative guidance mode
LET	launch escape tower
L/D	lift-to-drag ratio
RCS	reaction control system
SCS	stabilization and control system
SPS	service propulsion system
TFF	time of free fall
ΔV	incremental change in velocity

1. INTRODUCTION

A launch phase abort study for a high inclination (50 degrees) trajectory has been published, Reference 1. The launch vehicle trajectory used for data generation in that study was characterized by a highly lofted altitude profile. Consequently, entry loads in excess of the 16-g manned mission tolerance were encountered in free-fall abort simulations over a portion of the nominal trajectory.

An optimally shaped launch to insertion trajectory was suggested as a means of reducing the high entry g forces noted in Reference 1. The results of incorporating this optimum profile into an abort analysis identical in content to the original study are documented herein.

1.1 PURPOSE

The purpose of the study was to identify possible launch abort problems concerning entry loading, time of free fall (TFF), and landing range constraints and to determine launch abort mode capabilities and limitations. Specifically, the analysis was directed towards disclosing any relation between these considerations and the high inclination feature of the launch trajectory plane.

1.2 SCOPE

An optimum 50-degree inclination ascent to orbit trajectory was evaluated in terms of launch phase contingencies. The study was intended to update the results of an earlier report which used a nonoptimum launch trajectory in the abort analysis. This additional effort was concerned primarily with the effect of the reshaped trajectory profile on the entry load problem for nominal Mode II aborts noted in the original study. The parametric data required to assess this condition and other aspects of launch phase aborts were generated from the revised profile. It should be pointed out that high inclination orbits have been proposed for Apollo Applications Program (AAP) missions, and the trajectory profile used in this and the earlier study was planned for the AAP 1-A mission.

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2. INPUT DATA

The uprated Saturn 1 launch trajectory used for this study was derived, after certain modifications, from Reference 2. The trajectory profile in this reference reflects a spherical earth approximation and insertion occurs at a perigee altitude (87 nautical miles) referenced to the pad radius. For simulation purposes in this study, the trajectory was refined to include the earth oblateness effect. The nominal ascent-to-orbit trajectory parameters were generated from a precision integration program implementing the iterative guidance mode (IGM) for launch vehicle guidance. The trajectory was initiated at launch escape tower (LET) jettison and continues to insertion into an 87/140-nautical mile (perigee altitude/apogee altitude) orbit. Saturn IVB (S-IVB) cutoff was at 614.70 seconds ground elapsed time (g. e. t.) as compared to 614.06 seconds g. e. t. for the spherical earth simulation in Reference 2. The increase in burn time produced a 269.4 pound loss in insertion weight.

Nominal launch vehicle data obtained from Reference 2 are tabulated in Table 1. Spacecraft propulsion, weight, and aerodynamic characteristics were provided by Reference 3 and are presented in Table 2. One exception to the Reference 3 data was the command module (CM) weight of 12,250 pounds.

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3. ABORT MODE PROCEDURES

The method by which the spacecraft and crew recover from an inflight failure during the launch to insertion mission phase depends primarily on trajectory conditions at the point of failure. The basic modes of spacecraft launch aborts are (1) return to earth and (2) contingency orbit insertion. Where there is overlapping coverage by these two methods, certain criteria such as a time critical situation would be used in deciding upon the more feasible approach. The following is a brief description of the launch abort modes (excluding Mode I, which was not a part of the analysis) designated for AAP Mission 1-A.

Mode II - Aborts of this type consist of the spacecraft separating from the launch vehicle and flying a free-fall, full-lift entry to an Atlantic Ocean landing. The Mode II region begins at LET jettison and continues to the point where the Mode II maneuver sequence results in a landing 3500 nautical miles downrange from the launch pad.

Mode III - This recovery procedure involves a retrograde attitude service propulsion system (SPS) burn of 575-feet per second incremental velocity (ΔV). SPS ignition occurs at 125 seconds after the abort signal. The AAP-1A abort modes requiring the SPS utilize this delay time for separation from the launch vehicle and orientation to the desired burn attitude. A half-lift CM entry completes the procedure. Mode III begins at the Mode II 3500-nautical mile landing point and ends when the landing point following the Mode III sequence is 3500 nautical miles. The ΔV magnitude used in this procedure (575 feet per second) represents the maximum ΔV capability for AAP-1A launch abort maneuvers. The SPS propellant allotment is significantly reduced for this mission when compared to Apollo. This is due to greater payload requirements for the long duration AAP flights.

Mode IIIA - Varying the SPS ΔV up to the maximum available (575 feet per second) in a posigrade attitude in order to achieve an Indian Ocean landing at 7500 nautical miles downrange (with a CM half-lift entry) constitutes the Mode IIIA abort procedure. This type of abort maneuver begins at the Mode III abort limit (3500 nautical miles) and continues until the SPS posigrade burn required to land at 7500 nautical miles with a half-lift entry is zero. Mode IIIA coverage is actually available beginning at the point corresponding to an SPS ΔV burn of 575 feet per second.

Mode IIIB - This procedure consists of an SPS retrograde burn maneuver which is also targeted to an Indian Ocean splashdown, following a half-lift entry, at 7500 nautical miles. It begins at the point where Mode IIIA aborts end and extends past nominal insertion to the point where the maximum ΔV capability (575 feet per second) is reached.

Mode IV - The abort to orbit (Mode IV) procedure is used to insert the spacecraft into an orbit having a perigee altitude of at least 75 nautical miles. Deorbit capability from any point in the contingency orbit must be considered when designating the Mode IV abort regime. The maneuver itself employs the SPS in the posigrade burn attitude to supply the necessary velocity increment to place the spacecraft into the desired orbit.

The posigrade and retrograde spacecraft attitudes used for the SPS abort burn maneuvers are shown in Figure 1. The sequence of events for the launch abort simulations as used in this study is presented in Table 3.

4. NOMINAL AND LAUNCH ABORT TRAJECTORY CONSTRAINTS

Various ground rules are in effect during the launch phase to protect the crew in the event a contingency situation occurs. The trajectory limits corresponding to these guidelines are monitored as the nominal flight progresses and are also accounted for in the spacecraft launch abort maneuvers. The constraints pertaining to this analysis are as follows:

a) Entry loads - Trajectory conditions in the course of the ascent to orbit which would produce forces during a full-lift entry greater than 16g's for a free-fall abort from the nominal are to be avoided.

b) Time of free fall - This limit requires the free-fall time remaining above the entry interface of 300, 000 feet altitude to be at least 100 seconds. The purpose of this constraint is to provide adequate time for orienting the spacecraft prior to entry.

c) Landing range - In the event an abort during launch is dictated, consideration must be given to land impacts in choosing the appropriate spacecraft procedure. The land mass to be avoided is defined in terms of an interval of downrange distance from the launch pad along the nominal launch azimuth. For this study, the interval used was from 3500 to 7500 nautical miles.

The analysis performed in this study consisted of applying the preceding constraints to the launch trajectory described in Section 2 and to relevant launch abort simulations. Results of this investigation are presented in the following section.

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5. RESULTS

The graphical dynamic data required to adequately portray the objectives of this subtask are presented in Figures 1 through 15.

Figure 2 reflects inertial flight-path angle and altitude as a function of downrange distance from the launch pad. As a comparison, the reference trajectory from Reference 1 is shown. The obvious differences observed in both inertial flight-path angle and altitude will significantly change the forthcoming data presented in this report. The aforementioned differences are meaningful when making comparisons of these data to that of Reference 1. Figures 3 through 6 reflect the remainder of the nominal launch trajectory parameters from S-IVB ignition to insertion.

The TFF remaining above an altitude of 300, 000 feet at the time of launch vehicle cutoff along the nominal trajectory is shown in Figure 7. The results indicate that sufficient TFF remains prior to entry interface to orient the command module after the initiation of a free-fall abort. Figure 8 shows the effect on TFF when using the posigrade and retrograde maneuvering capabilities. These results indicate that posigrade and retrograde abort maneuvers should not be initiated below nominal S-IVB cutoff inertial velocity values of 22, 300 feet per second and 23, 300 feet per second, respectively.

Figure 9 represents free-fall aborts from the nominal trajectory as a function of inertial velocity at abort and maximum load factor encountered during entry. The results indicate that, for a Mode II type abort with a non-maneuvering full-lift entry, the maximum g limit line is not violated.

A ground track of the nominal trajectory (Reference 2) is shown in Figure 10. Because of possible land impacts, the area to be avoided following a suborbital abort lies between approximately 3500 and 7500 nautical miles downrange from the launch pad. Figure 11 reflects the landing range control available utilizing the SPS maneuvering and delta velocity capabilities and the CM aerodynamic capabilities as a function of inertial velocity at abort and downrange distance from the launch pad. Figure 12 portrays abort Modes II, III, IIIA, and IIIB as a function of the same landing range and velocity parameters shown in Figure 11. Note that Mode III

overlaps considerably into the Mode IIIA region and that Mode IIIB extends 614.75 seconds past the nominal insertion value. Abort Mode IV is defined in Figure 13 as a function of inertial velocity at abort, delta velocity required for contingency orbit insertion (ΔV_{COI}), and height of apogee following a Mode IV abort. Comparing Figures 12 and 13, note that Mode IV overlaps various portions of Modes III, IIIA and IIIB and that the capability exists, for inertial velocity values greater than 25,105 feet per second, to initiate one of the following:

- Insert into a contingency orbit and deorbit at a later time
- Mode IIIA abort up to inertial velocity values of 25,420 feet per second
- Mode IIIB abort for inertial velocity values greater than 25,420 feet per second up to 614.75 seconds after insertion into the nominal orbit

The effect of pitch attitude deviations from the nominal for a SPS posigrade maneuver is shown in Figure 14 as a function of SPS velocity required to achieve a 75-nautical mile perigee (contingency) orbit. Deorbit considerations were excluded.

Figure 15a shows the effect of flight-path angle variations upon the delta velocity required to achieve a 75-nautical mile perigee orbit. Note the Mode IV boundary capability line, which defines the ability both to reach a 75-nautical mile perigee altitude and to subsequently deorbit anywhere in the orbit. Figures 15b and 15c redefine the same parameters as in Figure 15a, with the one exception that they have altitude deviations from the nominal of a plus and a minus 2 nautical miles, respectively.

Figure 16 shows the 100-second TFF abort limit line, the 16-g abort limit line, and the nominal boost trajectory as a function of inertial velocity and inertial flight-path angle at abort.

6. CONCLUSION

Analysis of the free-fall trajectory data in Figure 9 indicates that entry g loads for a full-lift (Mode II) atmospheric entry would not violate the 16-g load factor limit. By noting the lower altitude profile used in the study when compared to the Reference 1 launch trajectory (Figure 2), the reason for the reduced loads can easily be seen. Application of the TFF and landing range constraints to the relevant abort maneuvers also produced satisfactory results (Figures 7 and 12, respectively). The Mode IV region was examined for altitude and attitude deviation effects on the SPS ΔV capability for contingency orbit insertion.

Results of this preliminary study of a 50-degree orbital inclination trajectory disclose that there is adequate coverage by the existing launch abort procedures for any anticipated failures during this phase of the mission. The high inclination aspect of the trajectory should not present any additional problems for operational launch abort planning.

Table 1. Launch Vehicle Data

Event	g. e. t. (sec)	Weight (lb)	Thrust (lb)	Weight Flow (lb)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (fps)	Inertial Azimuth (deg)	Inertial Flight-path Angle (deg)
Launch Escape Tower Jettison	178. 12	278, 287	224, 153	526. 05	286, 382	29. 45	-79. 61	7, 870. 0	52. 15	18. 27
S-IVB Mixture Ratio Shift	428. 12	146, 772	184, 153	426. 97	572, 481	33. 91	-74. 02	15, 091. 8	52. 16	0. 58
Orbital Insertion	614. 70	67, 109	0	0	556, 984	39. 67	-64. 90	25, 709. 9	56. 39	0. 00

*Referenced to the Fischer ellipsoid earth model.

**Geodetic latitude and longitude are positive north of the equator and east of the Greenwich Meridian, respectively.

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Table 2. Spacecraft Data

<u>Weight</u>	
At CSM/S-IVB Separation	27,217 lbs
At Atmospheric Entry (Command Module)	12,250 lbs
<u>Propulsion</u>	
SPS Thrust	20,290 lbs
SPS Weight Flow	64.38 lbs/sec

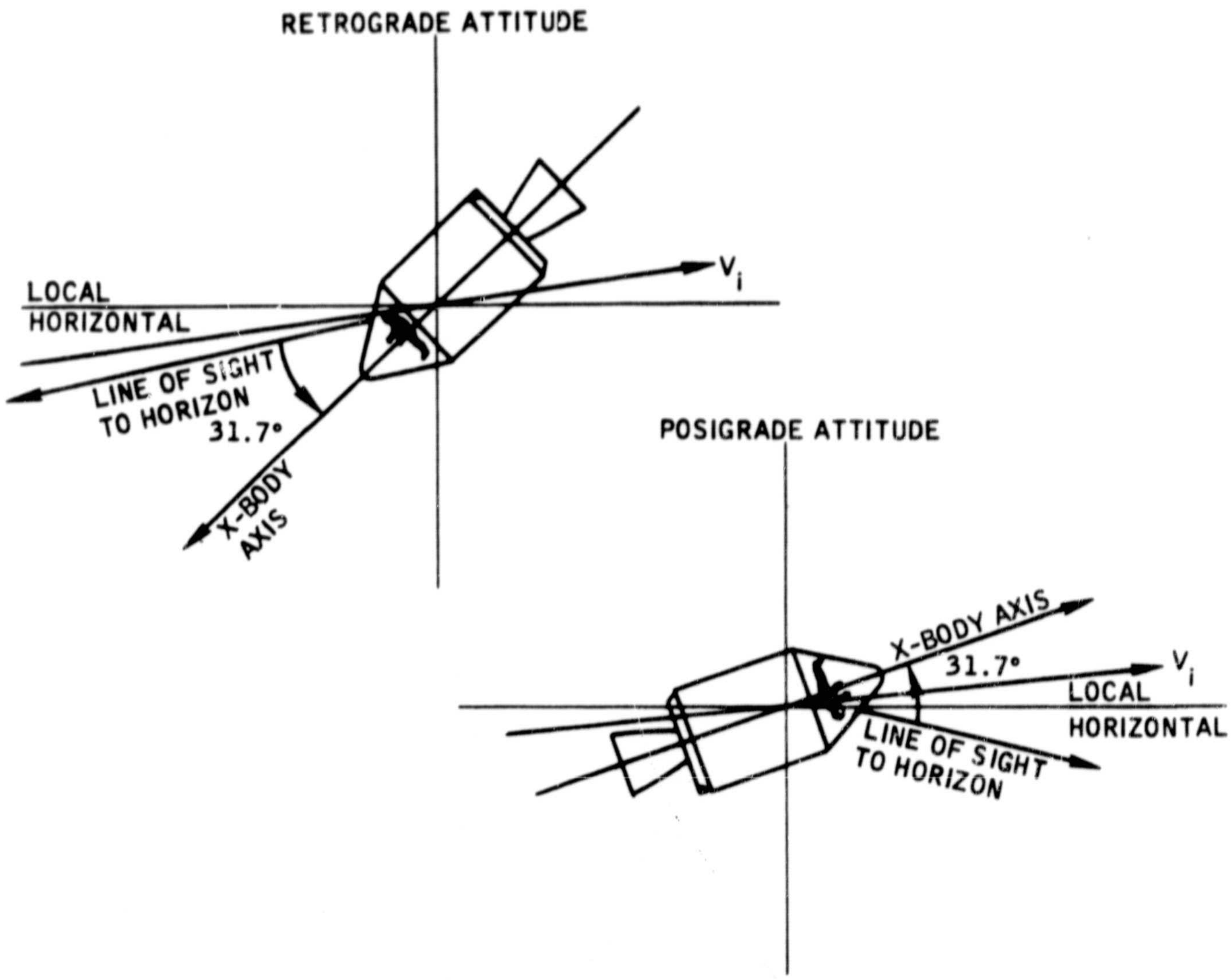
Command Module Aerodynamics

Mach	Trim Angle of Attack (deg)	L/D
0.2	169.7	0.327
0.4	165.4	0.332
0.7	161.9	0.303
0.9	158.7	0.348
1.1	152.5	0.464
1.2	152.3	0.466
1.35	150.7	0.495
1.65	150.4	0.475
2.0	150.2	0.457
2.4	150.6	0.445
3.0	151.5	0.431
4.0	153.7	0.398
Hypersonic	157.4	0.340

Table 3. Sequence of Events for Mode III, IIIA, IIIB, and Mode IV Launch Aborts

Time from Launch Vehicle Shutdown (min:sec)	Event
	Mode III, IIIA, IIIB
0:00.00	Launch vehicle cutoff (abort signal)
0:01.85	End of S-IVB tailoff
0:03.00	CSM/S-IVB separation, RCS direct ullage (Four jets) ON
0:23.00	Begin SCS orientation maneuver to SPS ignition attitude (Mode III and IIIB-retrograde, Mode IIIA-posigrade) - RCS direct ullage OFF
2:05.00	SPS thrust ON - SPS thrust OFF when: 1. SPS ΔV = 575 fps (Mode III) 2. Impact point = 7500 n mi (Mode IIIA and IIIB)
	Mode IV
0:00.00	Launch vehicle cutoff
0:01.85	End of S-IVB tailoff
0:03.00	CSM/S-IVB separation, RCS direct ullage (Four jets) ON
0:23.00	Begin SCS maneuver to posigrade attitude - RCS direct ullage OFF
1:50.00	RCS direct ullage ON*
2:05.00	RCS direct ullage OFF, SPS thrust ON - SPS thrust OFF when resulting $h_p \geq 75$ nautical miles

*Not simulated



NOTE: SPS RETROGRADE AND POSIGRADE MANEUVERS ARE INITIATED AT S-IVB CUTOFF PLUS 125 SECONDS. THE ATTITUDES PRESENTED ABOVE ARE THE REQUIRED SPACECRAFT ORIENTATIONS AT SPS IGNITION. THE SCS MAINTAINS THE INERTIAL ATTITUDE DURING THE ABORT MANEUVER WHICH CORRESPONDS TO THE RELATIVE ATTITUDE AT IGNITION.

Figure 1. Spacecraft Attitude at SPS Ignition for Launch Abort Maneuvers

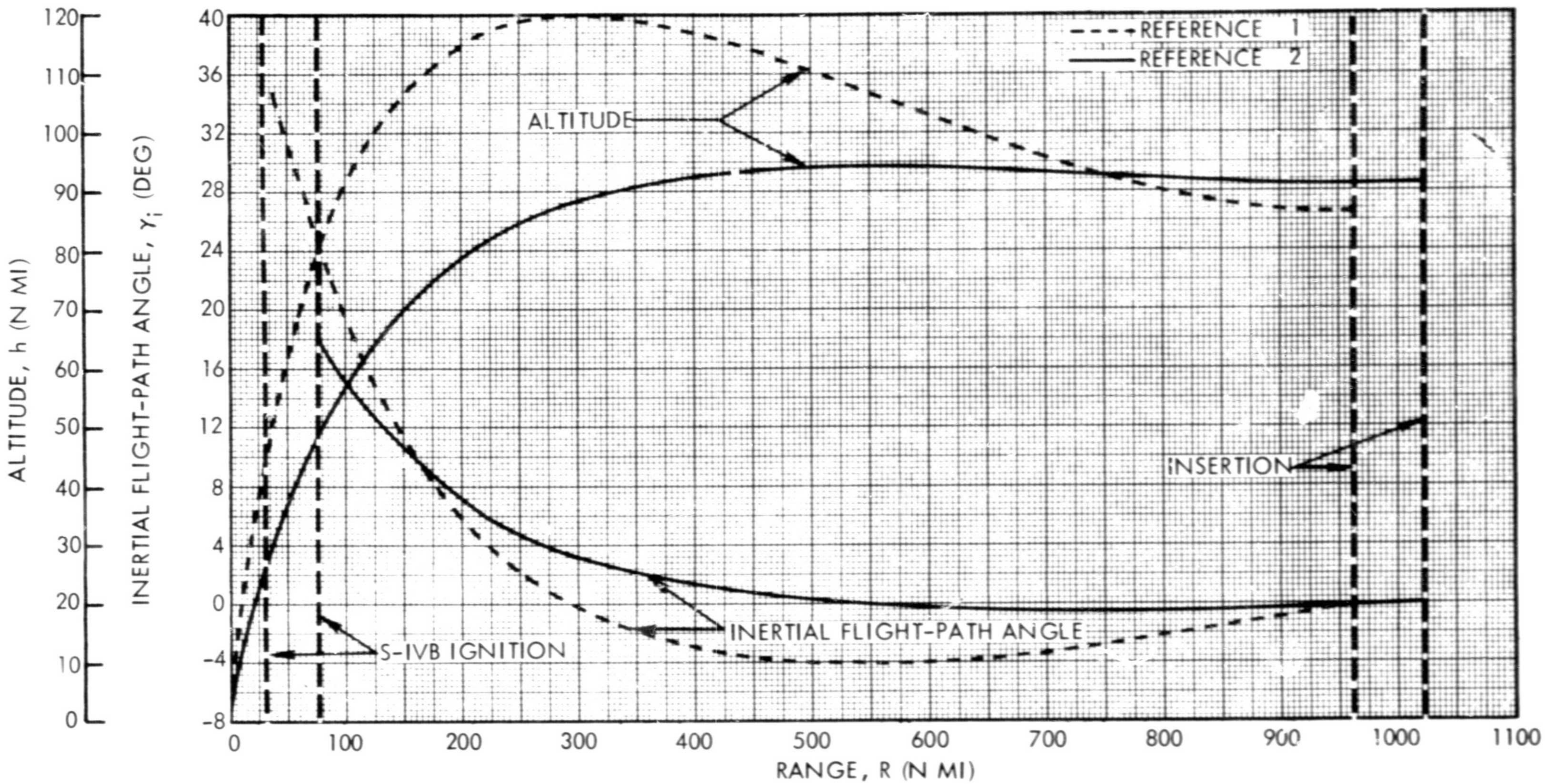


Figure 2. Altitude and Inertial Flight-path Angle as Functions of Range

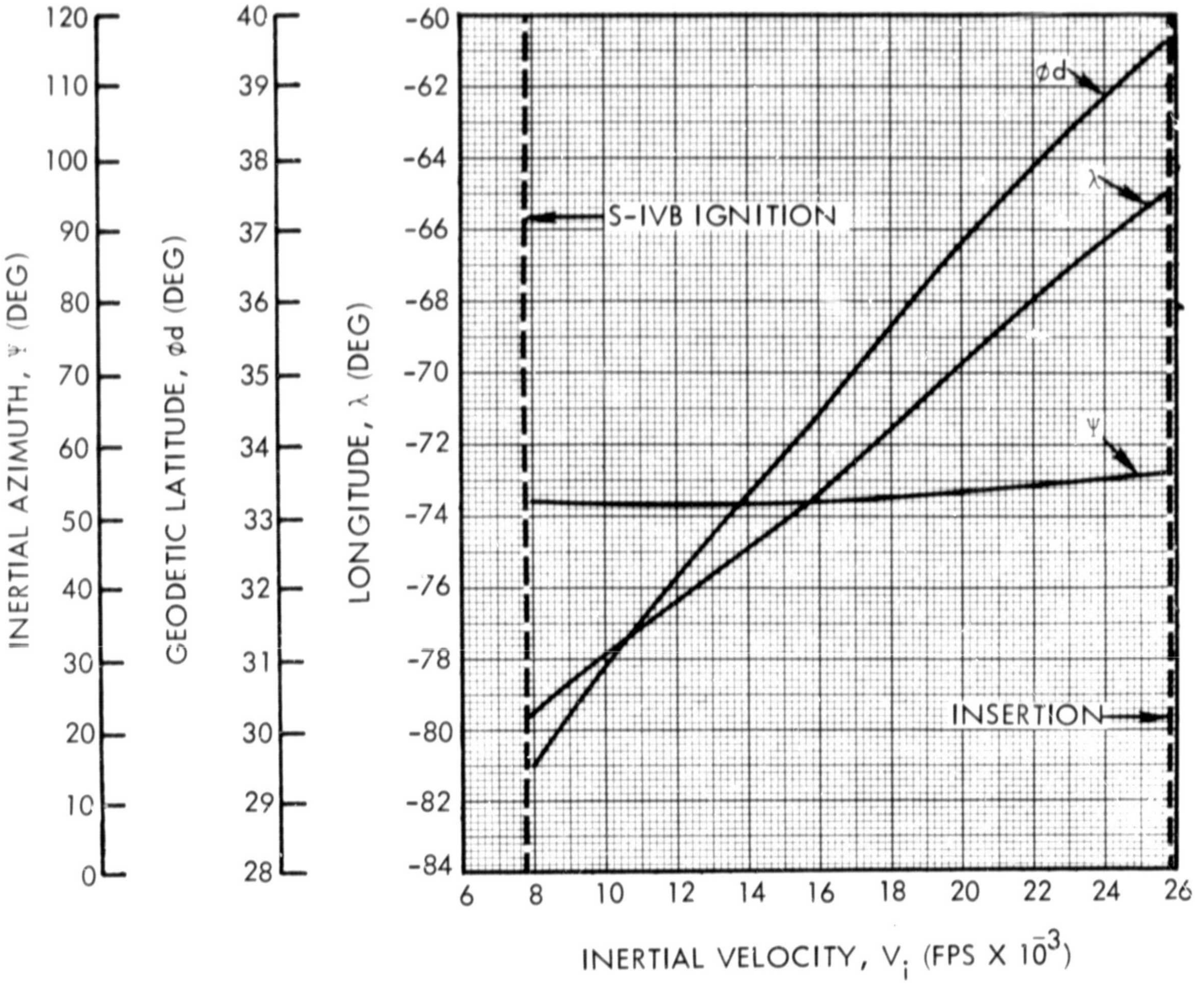


Figure 3. Inertial Azimuth, Geodetic Latitude, and Longitude as Functions of Inertial Velocity for the Nominal Launch Trajectory

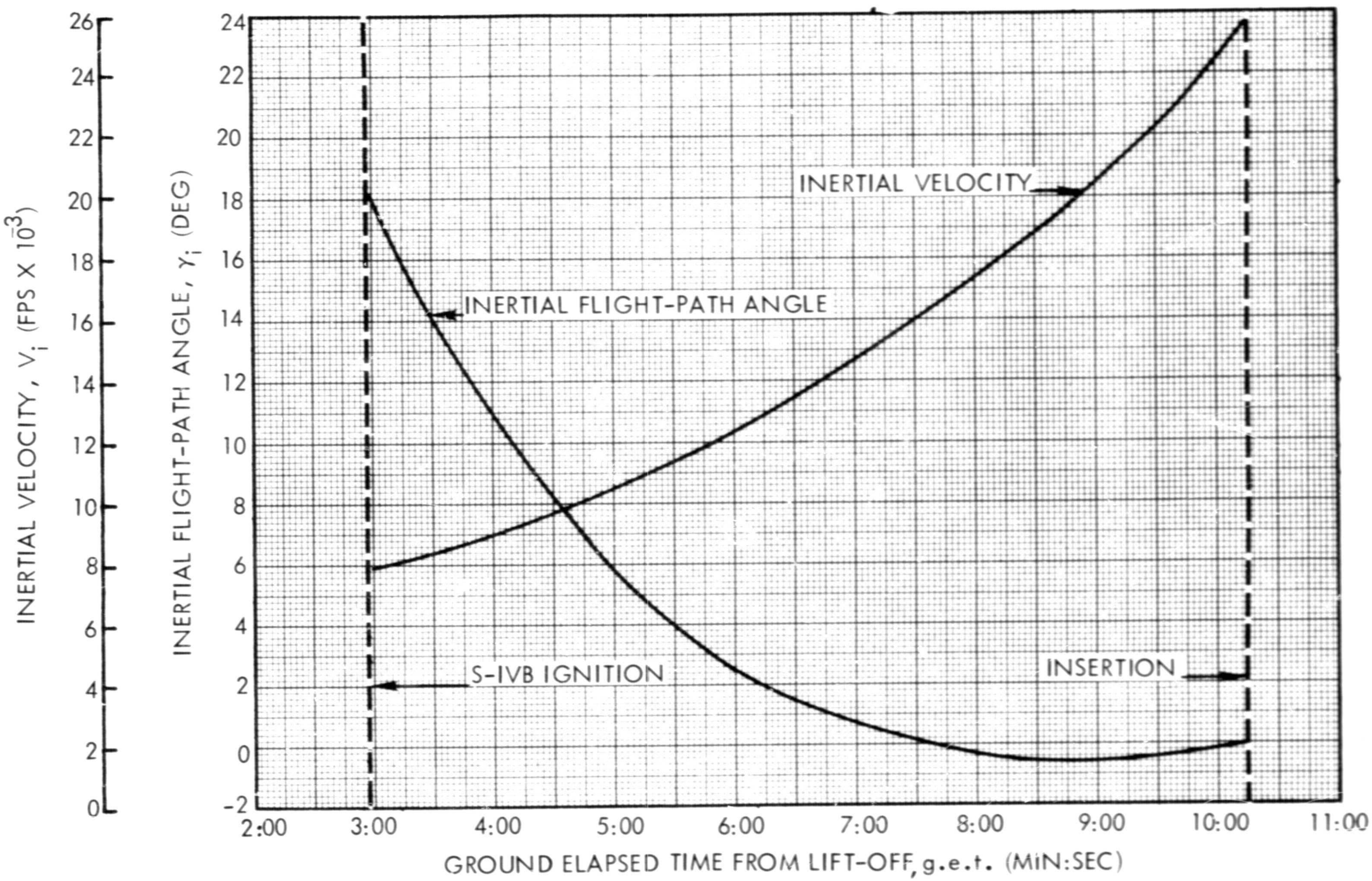


Figure 4. Time Histories of Inertial Velocity and Inertial Flight-path Angle for the Nominal Launch Trajectory

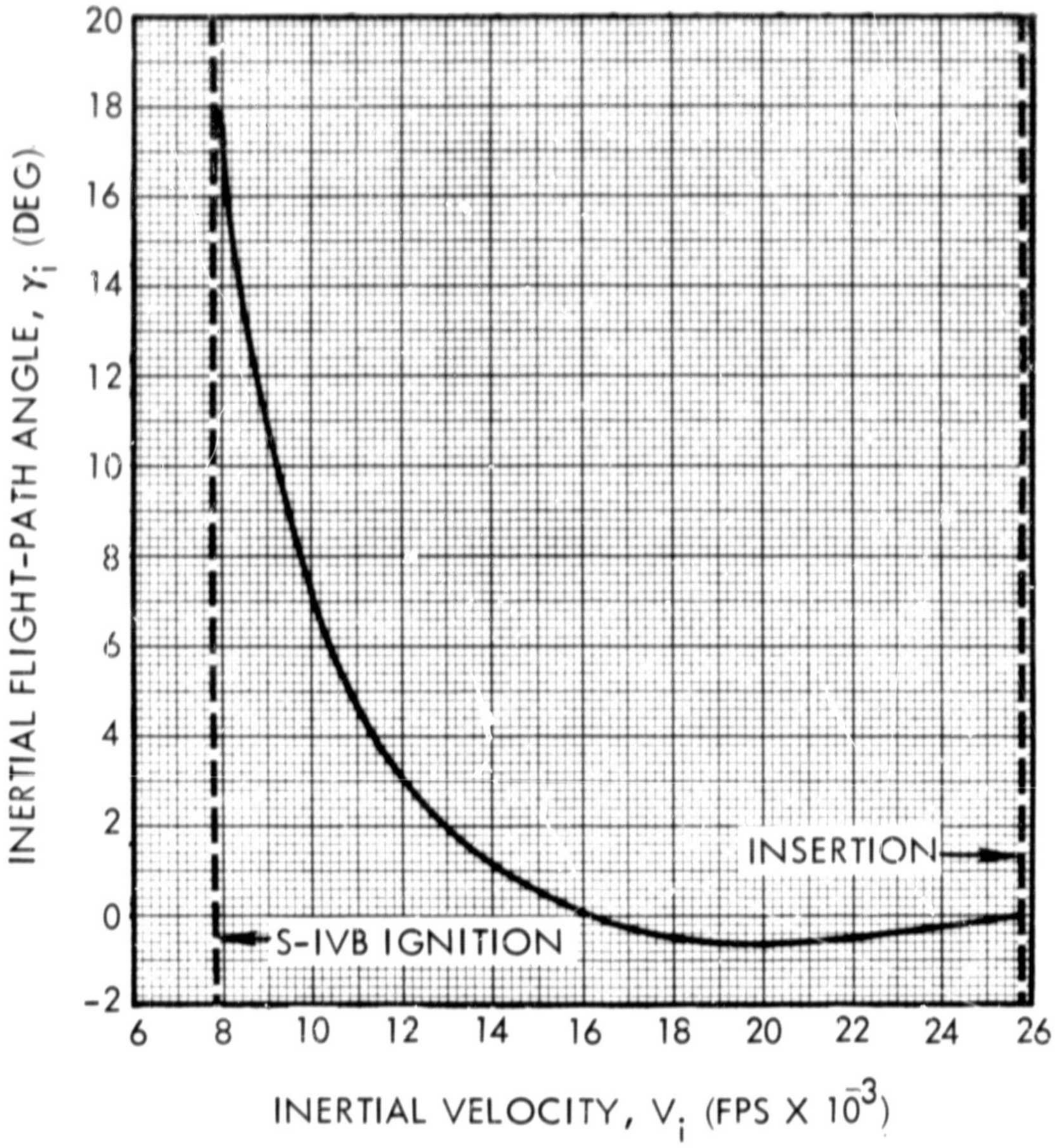


Figure 5. Inertial Flight-path Angle as a Function of Inertial Velocity for the Nominal Launch Trajectory

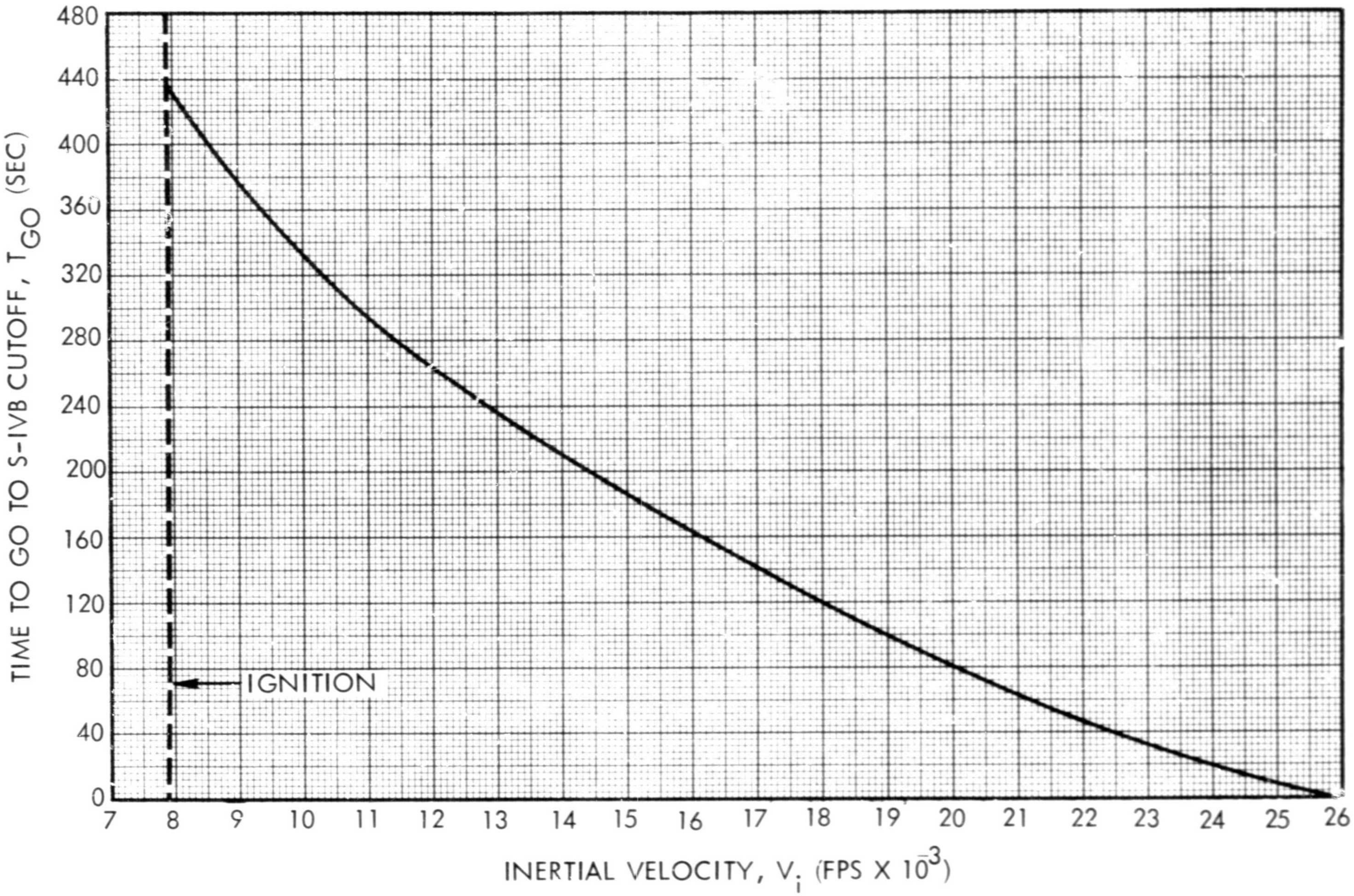


Figure 6. Time To Go to S-IVB Cutoff (Orbital Insertion) versus Inertial Velocity for the Nominal Trajectory

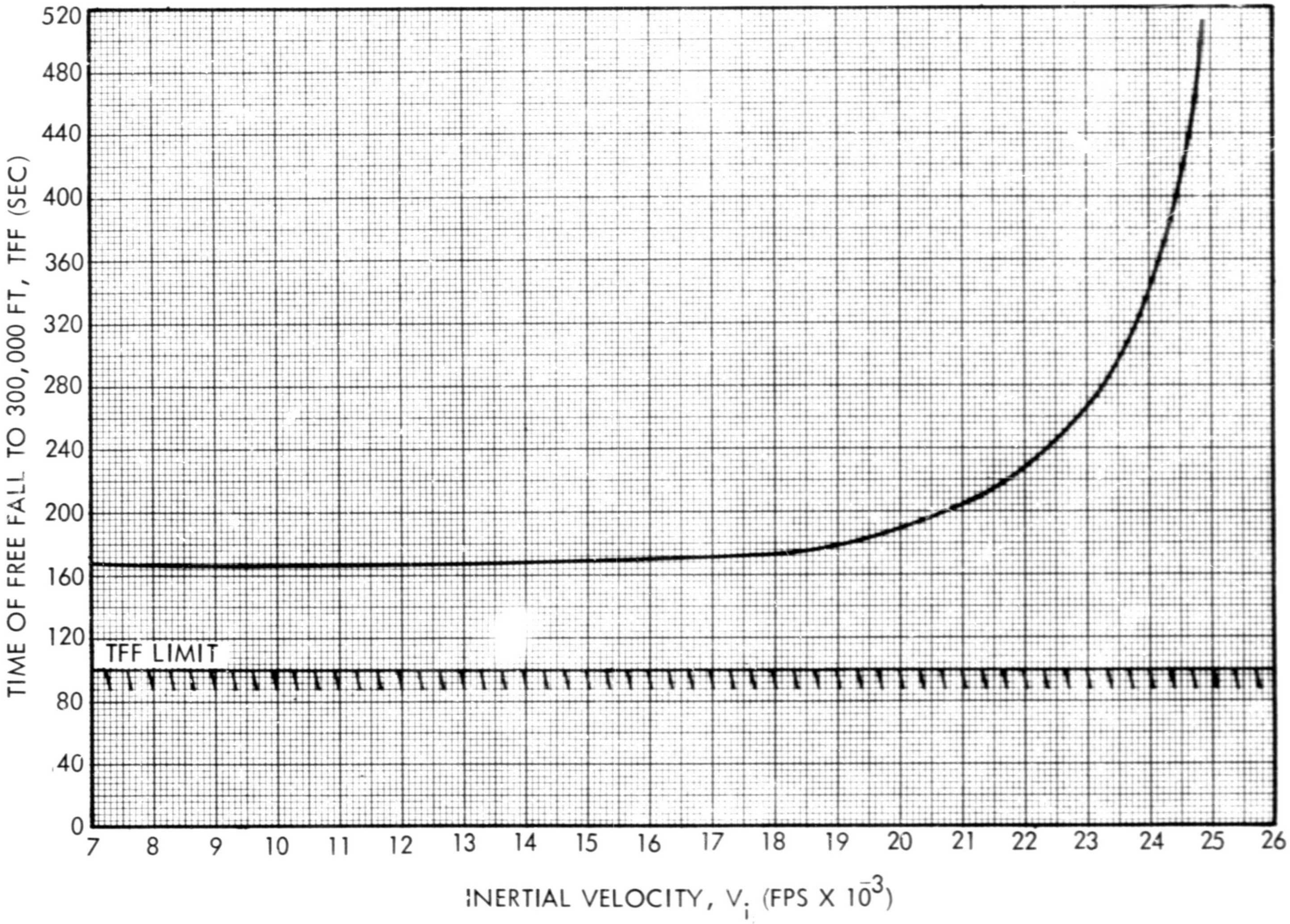


Figure 7. Time of Free Fall to 300, 000 Feet as a Function of Inertial Velocity along the Nominal Launch Trajectory

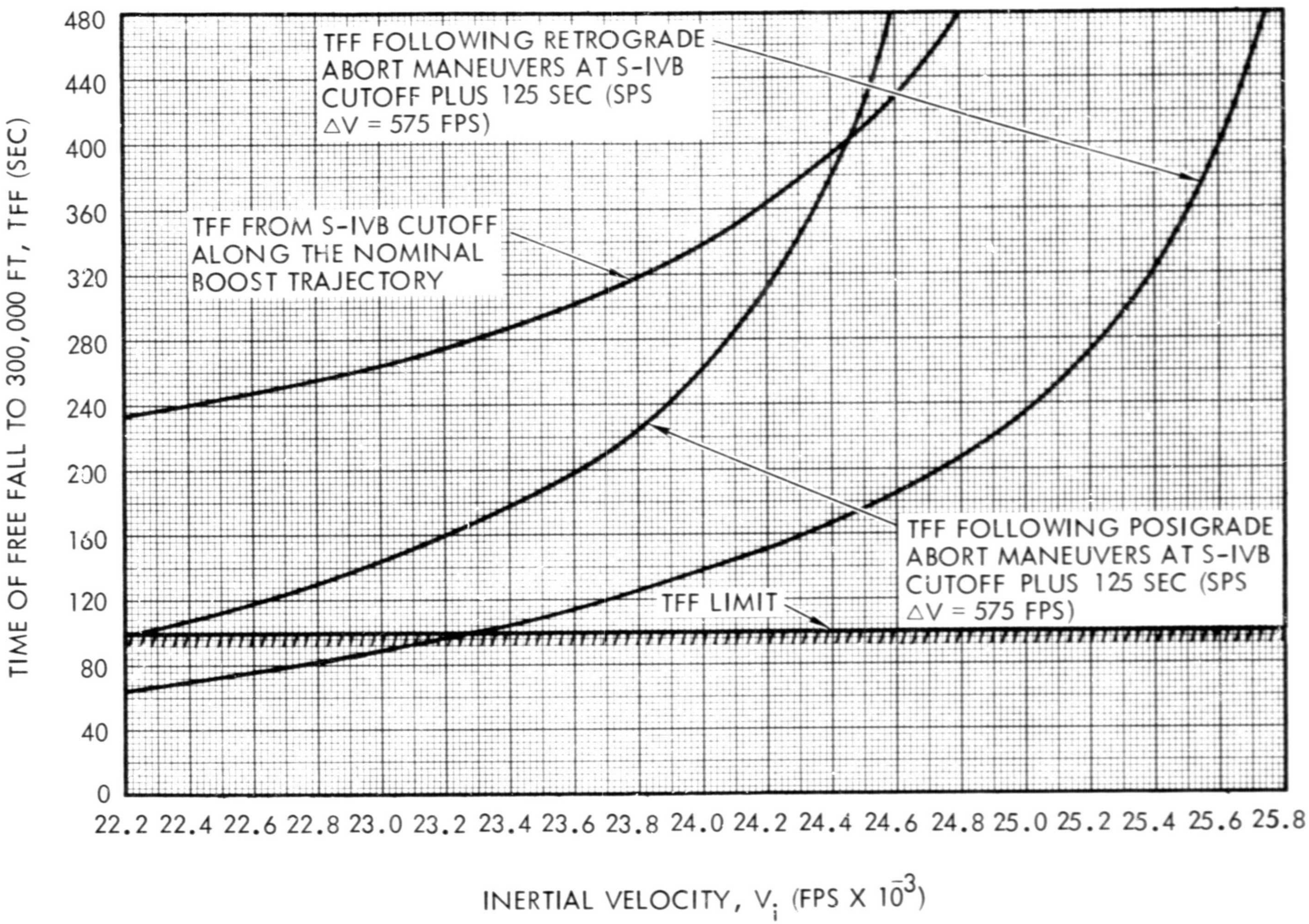


Figure 8. Time of Free Fall to 300, 000 Feet as a Function of Inertial Velocity along the Nominal Launch Trajectory and at SPS Abort Burn Cutoff

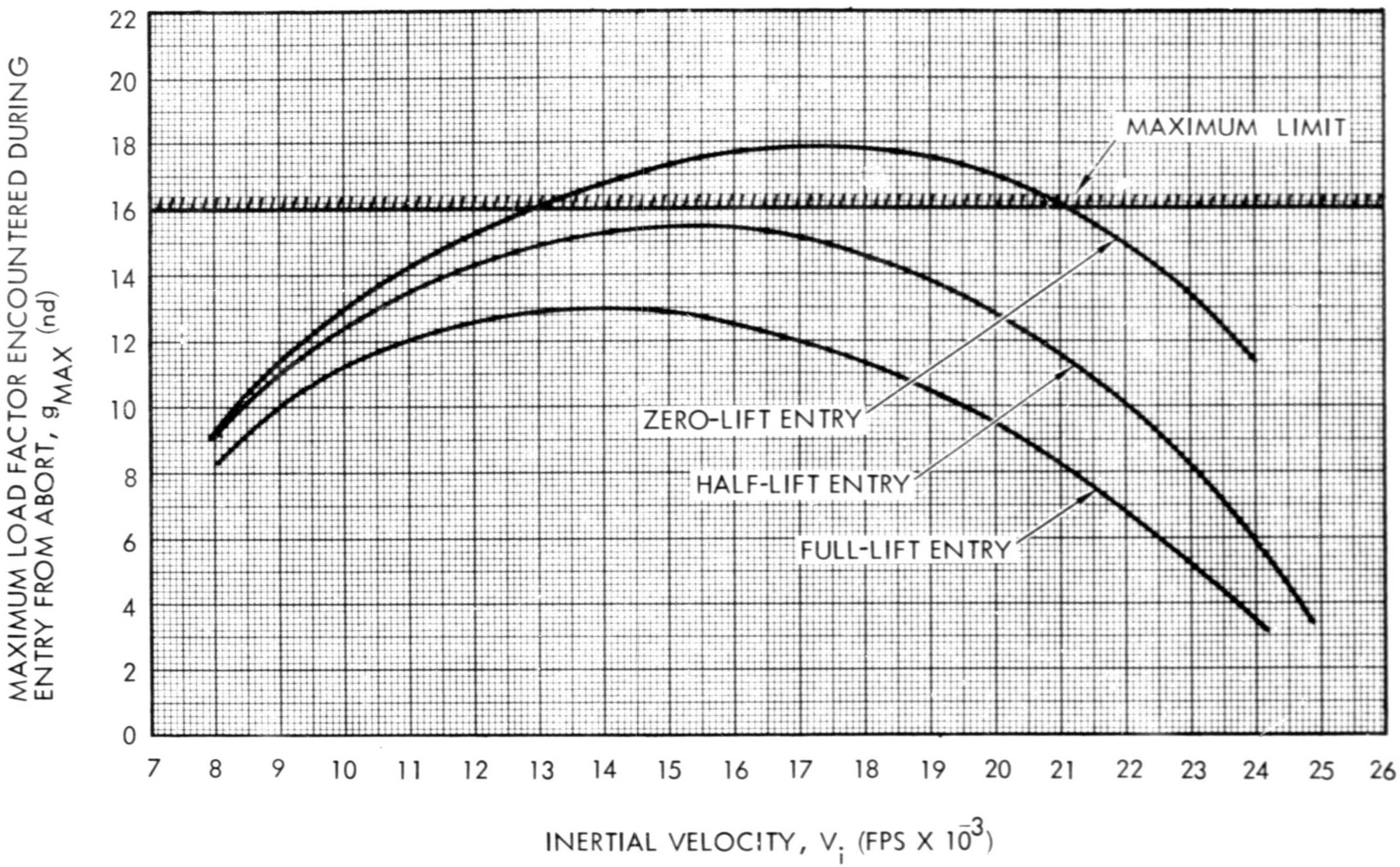


Figure 9. Maximum Load Factor Encountered During Entry for Free-fall Aborts from the Nominal Launch Trajectory

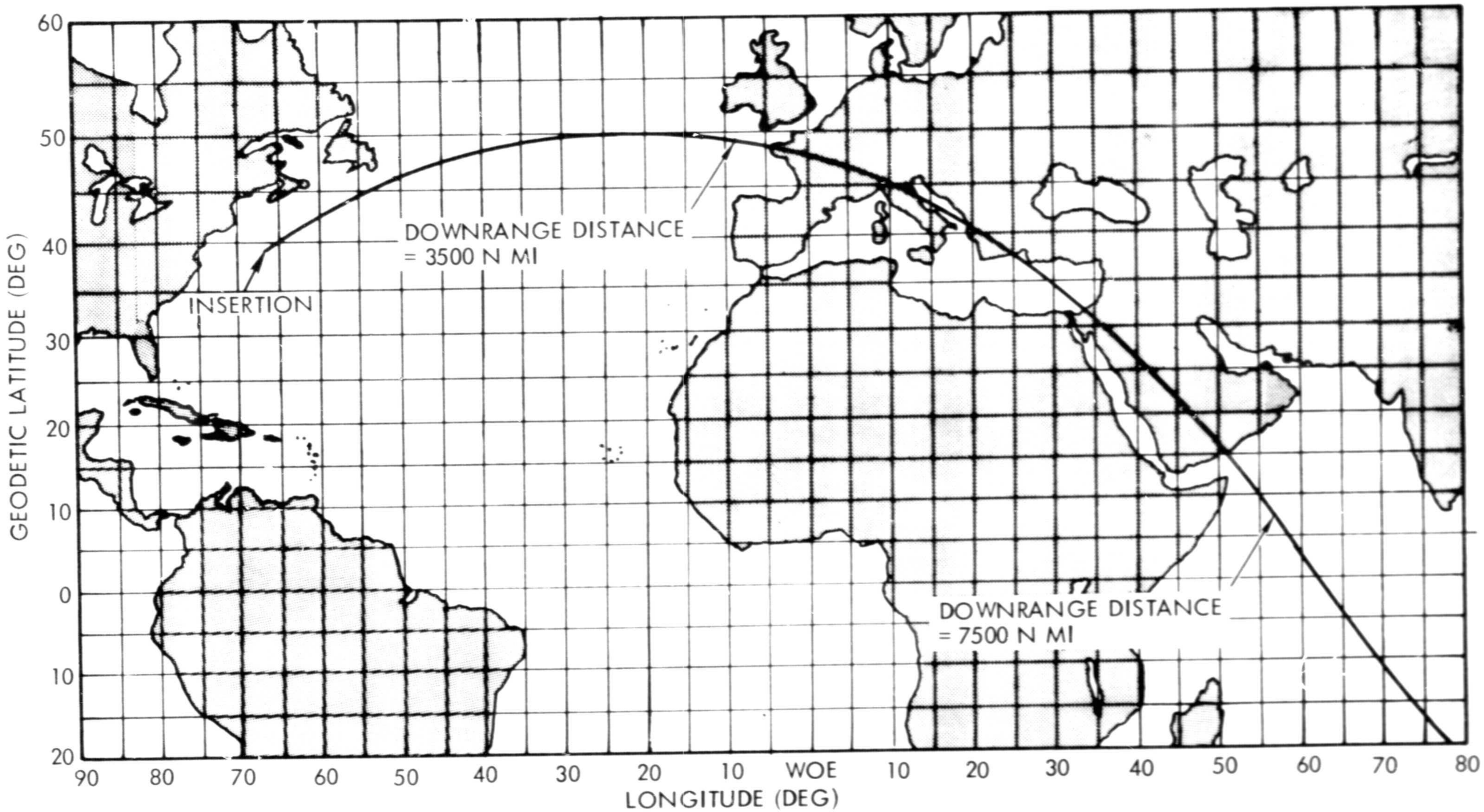


Figure 10. Ground Track for a 50-Degree Inclination Orbit

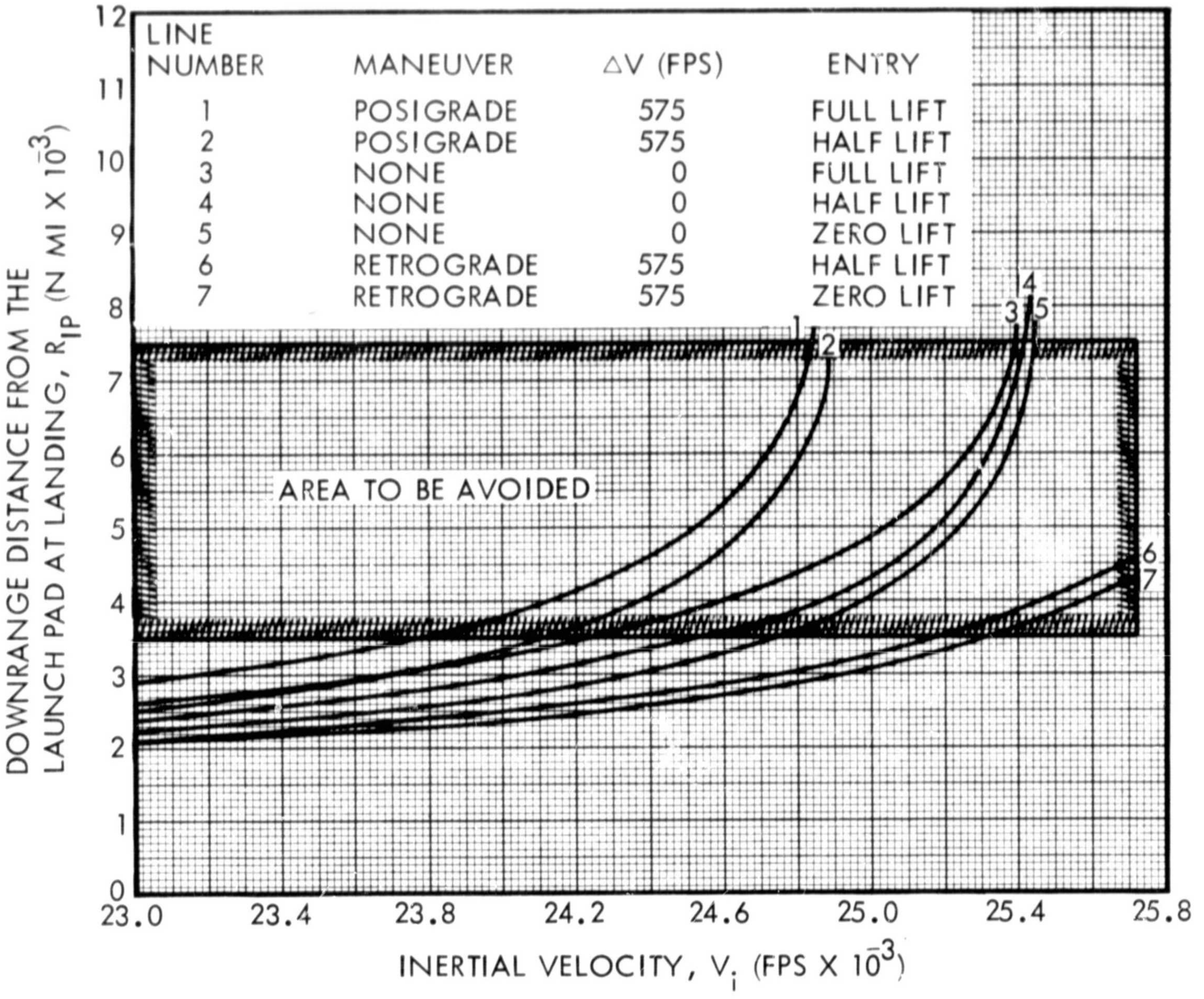


Figure 11. Landing Range Control for Various Abort Maneuvers from the Nominal Launch Trajectory

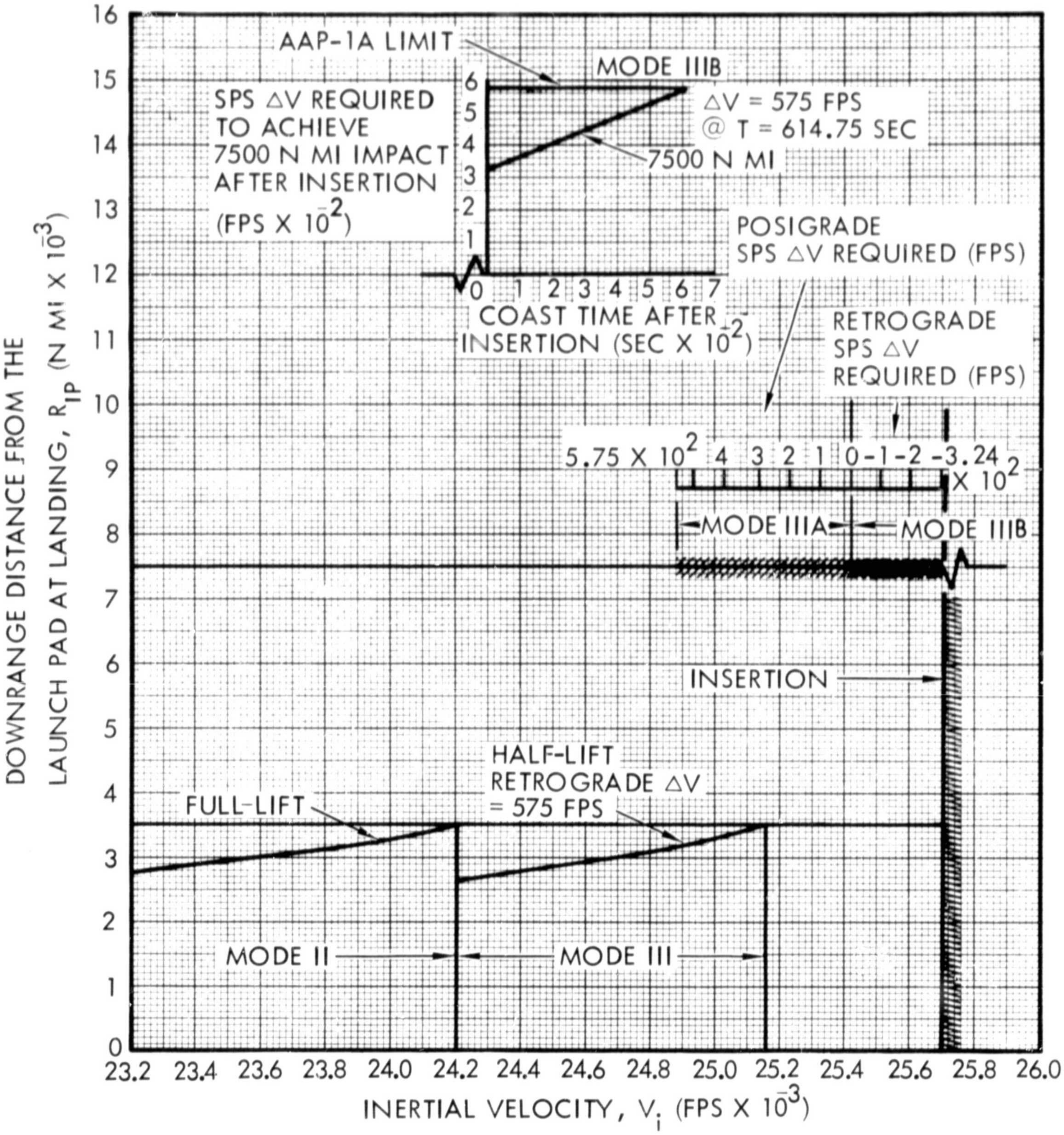


Figure 12. Return-to-earth Abort Mode Regions for the Nominal Launch Trajectory

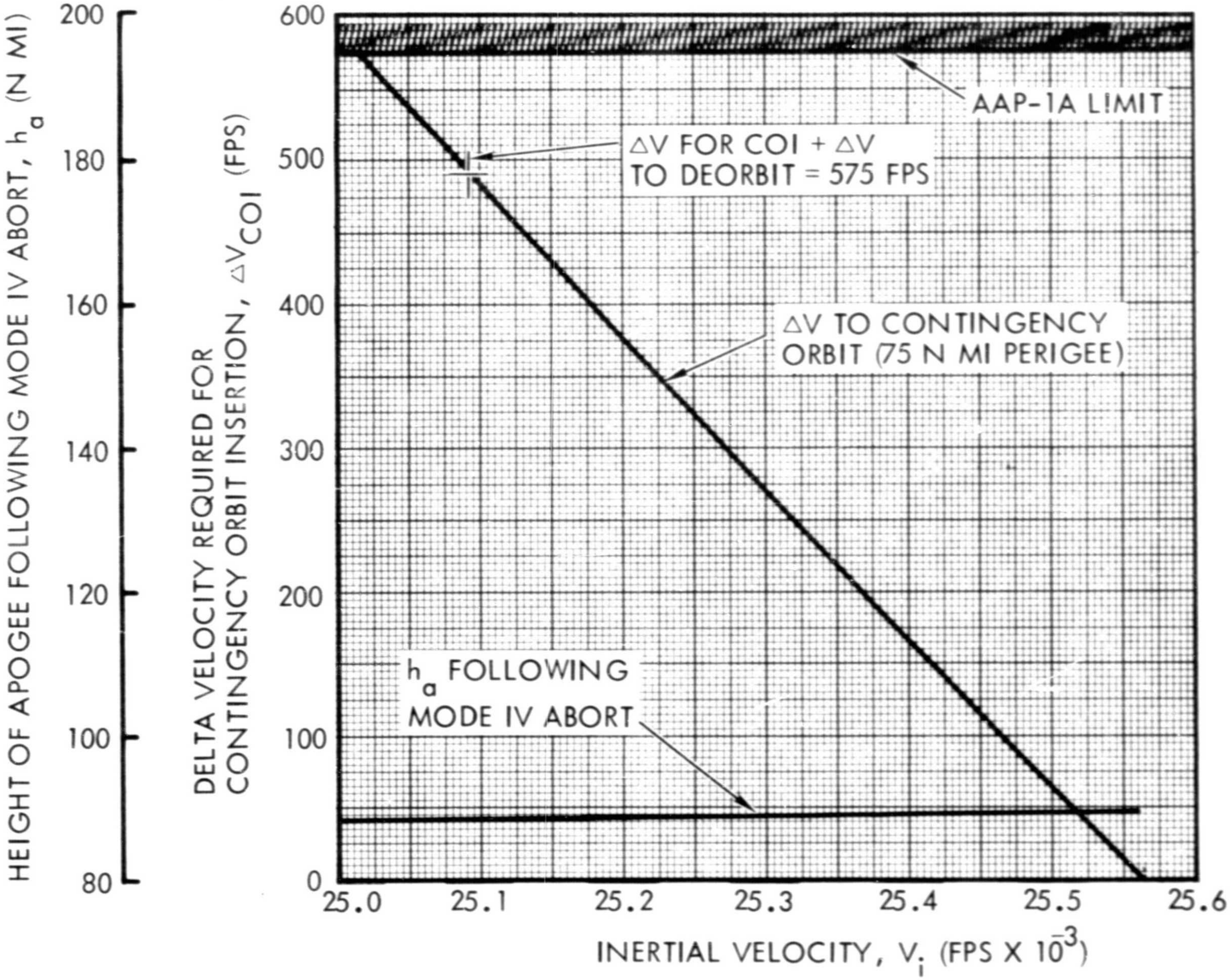


Figure 13. Delta Velocity Required for Contingency Orbit Insertion and Resulting Apogee Altitude for Mode IV Aborts from the Nominal Launch Trajectory

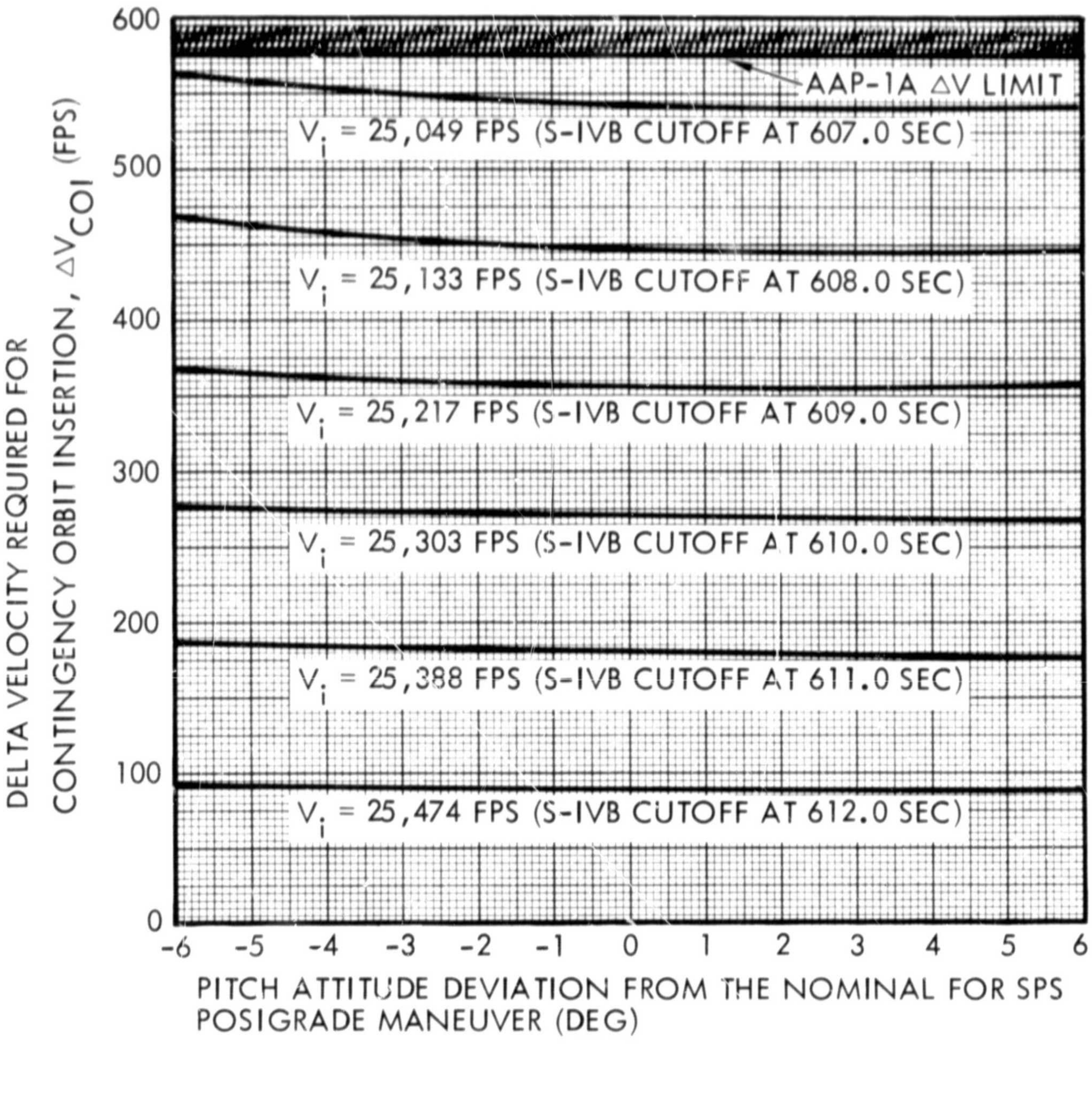
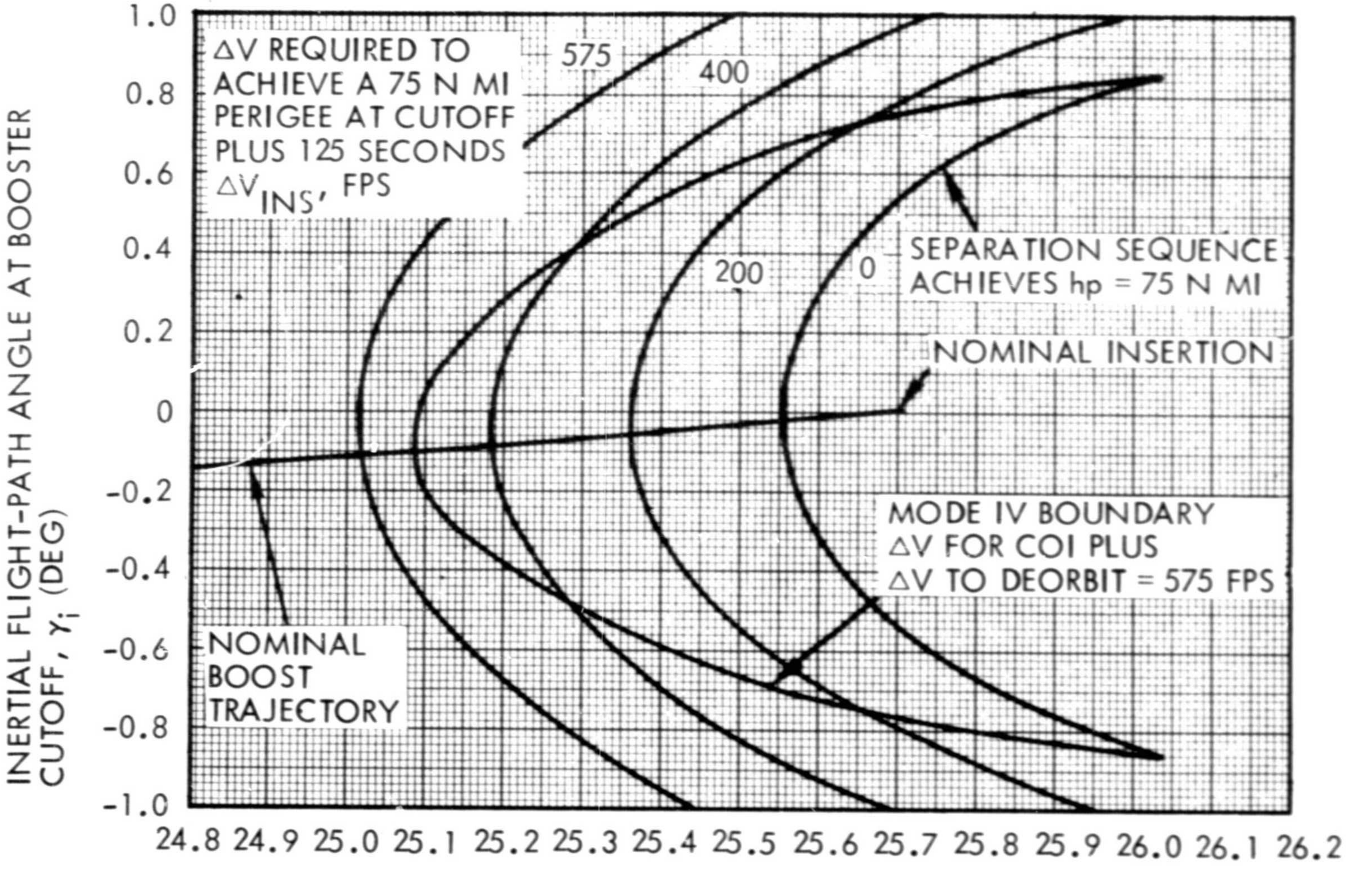
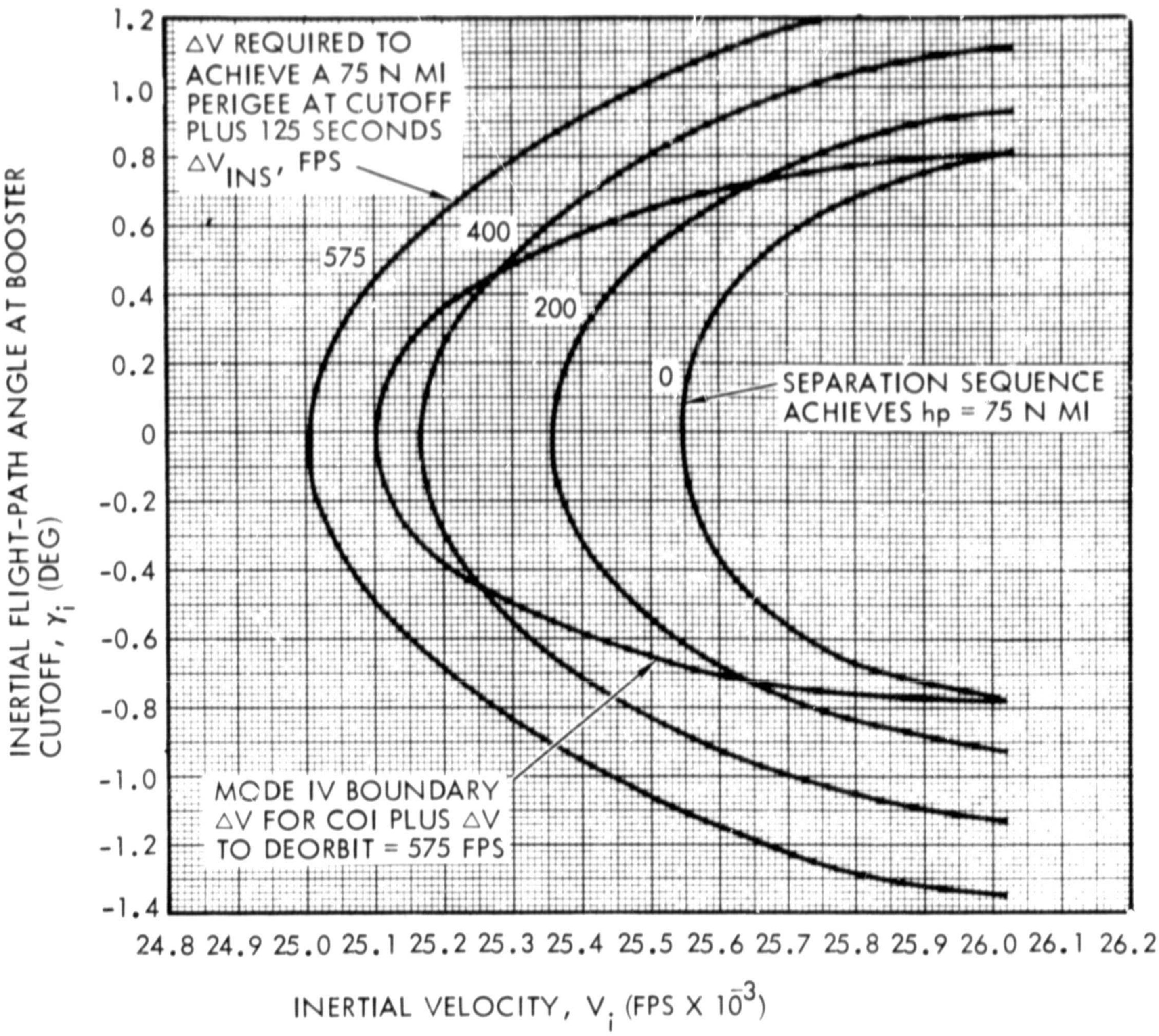


Figure 14. Effect of Pitch Attitude Deviations for Mode IV Aborts from the Nominal Launch Trajectory



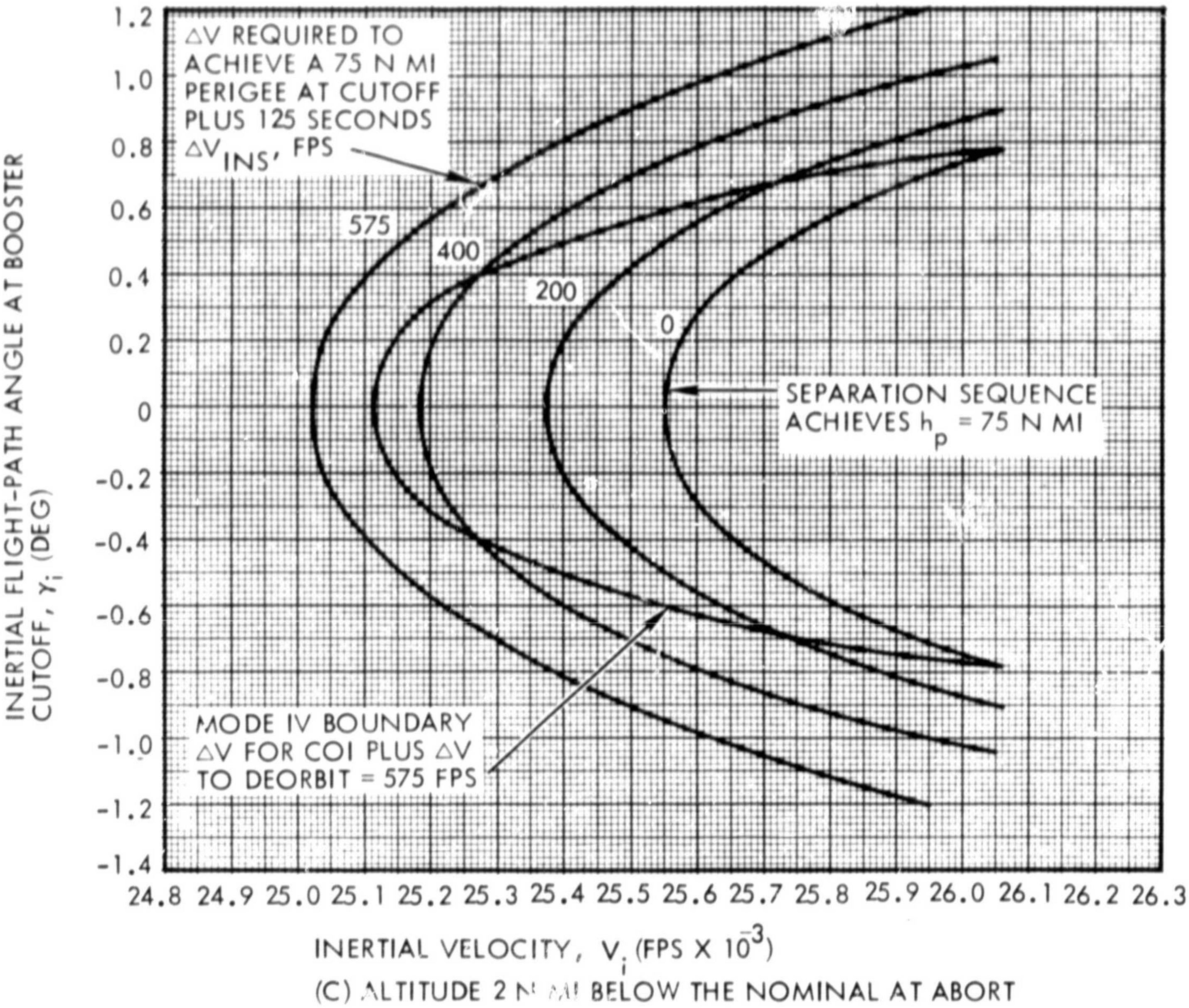
(A) NOMINAL ALTITUDE AT ABORT

Figure 15. Delta Velocity Required for Contingency Orbit Insertion at Booster Cutoff Plus 125 Seconds and Mode IV Boundary as a Function of Inertial Velocity and Flight-path Angle at Booster Cutoff



(B) ALTITUDE 2 N MI ABOVE THE NOMINAL AT ABORT

Figure 15. Delta Velocity Required for Contingency Orbit Insertion at Booster Cutoff Plus 125 Seconds and Mode IV Boundary as a Function of Inertial Velocity and Flight-path Angle at Booster Cutoff (Continued)



(C) ALTITUDE 2 N MI BELOW THE NOMINAL AT ABORT

Figure 15. Delta Velocity Required for Contingency Orbit Insertion at Booster Cutoff Plus 125 Seconds and Mode IV Boundary as a Function of Inertial Velocity and Flight-path Angle at Booster Cutoff (Concluded)

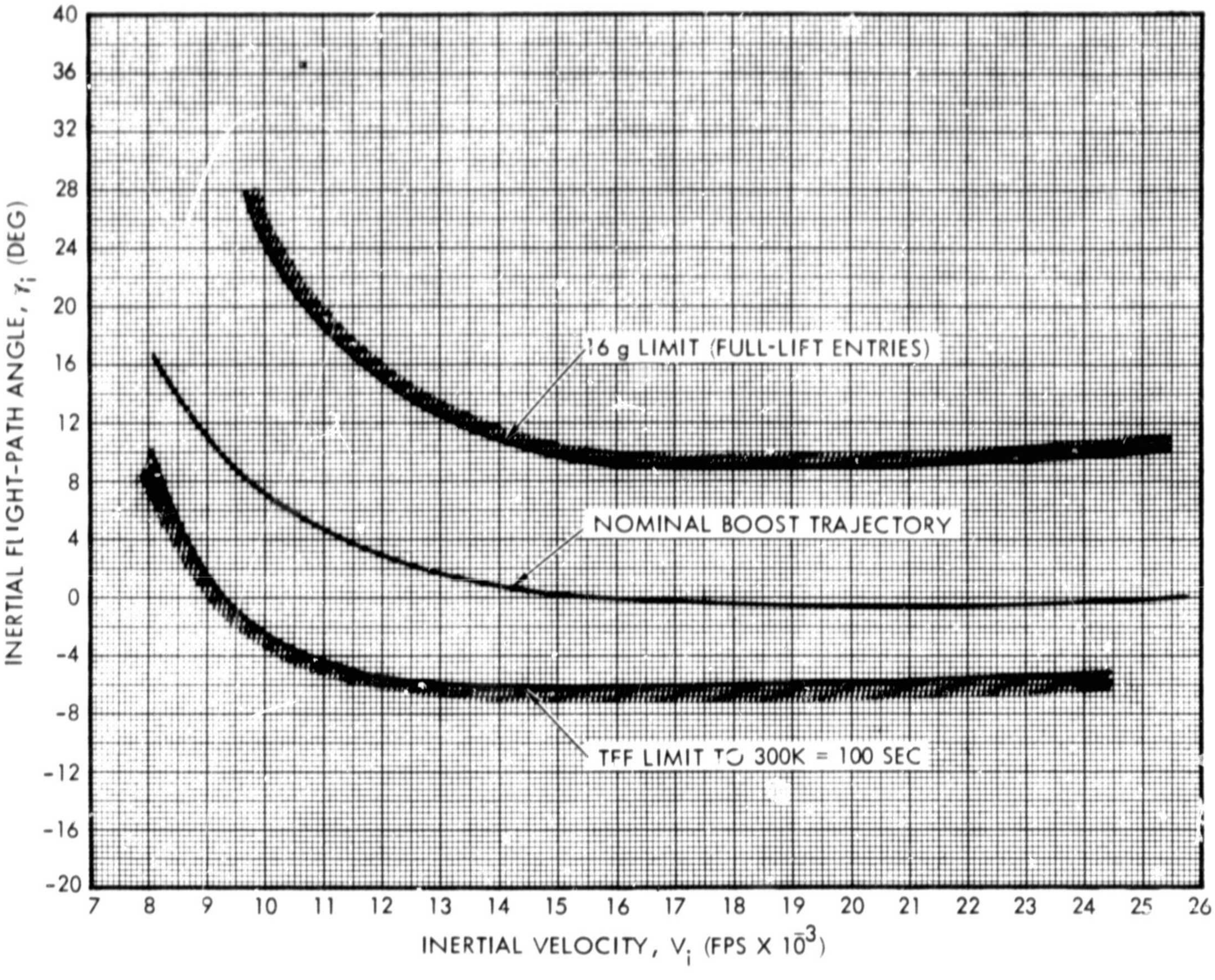


Figure 16. Trajectory Flight Limits Following LET Jettison

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